Evaluation of the Root Disease Indicator used in the Forest Health Monitoring Program

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ABSTRACT

As an indicator of forest health, the USDA Forest Service's Forest Health Monitoring program seeks to quantify the incidence and severity of root diseases in forests. The program's proposed technique involves excavating main primary roots on a tree's north and south sides out 1m from the base and looking for symptoms and signs of root disease. We simulated this technique on data collected from complete root system excavations of 11 ponderosa pines, 20 lodgepole pines, and 16 Douglas-fir and grand firs. The probability of detecting at least 1 symptomatic root with this 2-root technique was 0.85 on Douglas-firs and grand firs involved in a root disease complex, 0.77 for lodgepole pine infested with *Armillaria*, and only 0.56 for ponderosa pines infested with *Heterobasidion annosum*. The probability of detection increased as more roots were sampled. When 3 roots were sampled, the probability of detection increased to 0.82, and 0.80 for lodgepole pine and ponderosa pines respectively. Sampling a fourth root increased the probability of detection only slightly to 0.87 and 0.93. None of the probabilities of detection using 1, 2, 3 or 4 roots were good predictors of the proportion of root system with symptoms.

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Root diseases contribute significantly to the decline and mortality of forests. Unlike above ground pests, root pathogens are difficult to detect and quantify, and thus are often overlooked. In the Forest Health Monitoring (FHM) program, root condition will be examined using techniques derived by Alexander and Carlson (1989) and Alexander (1989). These techniques involve selecting northernmost and southernmost buttress roots of a tree, and excavating them to a distance of about 3 feet from the base of the tree, and examining the exposed roots for symptoms of root disease.

This technique has not been evaluated on root diseased trees in western forests. Zeglen (1991) has studied root systems in a lodgepole pine stand infested with Armillaria ostoyae in northern Utah. Baker et al. (1991) examined the incidence of annosus root disease and other root pathogens in a stand of Douglas-fir and grand fir in northern Idaho. An additional study is underway to develop a method for sampling ponderosa pine stands for annosus root disease. The results reported here are from simulated sampling using FHM techniques on these three data sets.

METHODS

Data were collected from three disease situations. The lodgepole pine stand in northern Utah was infested with Armillaria ostoyae, the ponderosa pine stands were infested by Heterobasidion annosum, and the Douglas-fir and grand fir stand in northern Idaho was infested by a disease complex involving Heterobasidion annosum, Armillaria spp., Inonotus tomentosus, Phaeolus schweinitzii, and Poria subacida. There were no above-ground symptoms evident in any of the lodgepole pines, Douglas-firs, or grand firs. One of the ponderosa pines was dead.

Only trees with root disease were included in the analysis. Twelve ponderosa pines were examined, 20 lodgepole pines, and 16 Douglas-fir or grand firs were examined. For each root segment, the following data were available: stump number, root number, length, condition (which described symptoms) and grid location (within a 20 X 20 cm grid). The first analysis combined all the roots from a given study. The direction which the root left a stump was determined from plot maps. The grid cells corresponding to north, south, east and west were identified. When roots left the stump in one of these cells, their direction was obvious. When they left in cells that were, for example, southeast the root was followed until it could be determined if it was more "southerly" or more "easterly". Each main root was examined to a distance of 1m. Roots were assigned to one of three categories: infested within 1m (detected); uninfested within 1m but infested beyond 1m (false negatives); and uninfested (failures). The probability of detecting root disease for each disease situation and each tree was then computed as follows. The probability of detecting a diseased root on any side of the tree is simply the proportion of roots with symptoms within 1m of the stump. Roots without symptoms, or roots with symptoms beyond 1m would not be detected. The probability of detecting a root disease during sampling in two or more directions from the stump can be computed most directly by subtracting the probability of detection from 1 for each direction to be sampled, and multiplying these probabilities (of not detecting symptoms) to give the probability of not detecting symptoms (a failure) in n tries. The probability of detecting at least one root is then simply the difference between the probability of failure and 1.

For example:

p(North) or p(South) or p(both) = 1 - (q(North) * q(South)

where

p is the number of symptomatic roots within 1m of the stump/total roots
q is 1 - p, or the proportion of non-symptomatic roots within 1m of the stump

In the second analysis, we computed the probability of detecting symptoms for each tree. The same analysis was done to determine probabilities. As a measure of accuracy, the mean of the probabilities of detection was computed. Since all trees were infected, this mean should approach 1. The standard deviation of the probability estimates gives some indication of the precision of the simulated sampling techniques.

Simple linear regression was used to examine the relationship between the probabilities of detection and the proportion of each root system with symptoms.

The proportion of root functionality, expressed as an estimate of the cross-sectional area of the root affected by the symptoms, was not computed. We rarely encountered dead root tips; most of the symptoms observed in these affected only a portion of the cross-sectional area, and the cambium usually remained alive in the area of the symptoms.

RESULTS AND DISCUSSION

The numbers of roots detected for each study are in Tables 1,3, and 5. If only one root were sampled from the north side of the ponderosa pines, the probability of selecting a root infected within 1m is 15/44, or .34 (Table 2). Conversely, the probability of selecting a root without symptoms within 1m of the stump is 0.66. Thus, 66% of the time a tree would be considered uninfected, even though it was actually infected. As roots are sampled from different directions, the probability of detection increased.

The probability of detecting a single symptomatic root was greater for the lodgepole pines infested with Armillaria (Table 4), and greatest for the mixed conifers affected by the disease complex (Table 6). Armillaria is known as a pathogen that attacks at the root collar. Thus, sampling near the stump would be effective for this pathogen. In the Douglas-firs and grand firs, we observed a brown discoloration that appeared to move outward from the stump. Heterobasidion annosum was associated with this brown discoloration, and was also observed on incubated stump disks. However, the distribution of the other pathogens present in this stand is poorly understood. If the other pathogens are not associated with the stump, the FHM technique would miss them. Studies are planned to learn more about the pathogen distribution on this study site.

The relationship between the proportion of roots with symptoms and the probability of detection was not strong (Tables 10-12; Figs. 1-3). Further analysis must be done if the FHM technique is to provide a reliable estimate of disease severity for individual trees.

Is this technique accurate? For ponderosa pines with annosus root disease, the improvement in accuracy of FHM technique over a coin flip does cannot justify the effort. Exposing additional roots does little to improve the accuracy of detection. Annosus root disease, at least on these trees, occurs out on the lateral roots, beyond 1m from the stump. Extra effort within 1m of the stump is wasted. In contrast, sampling additional roots does improve the accuracy of detecting symptomatic roots in lodgepole pine. In this situation the root disease is occurring on most trees within 1m of the stump. In the mixed conifer stand, there was so much disease that no matter how we looked we would detect it.

Is the FHM technique precise? In ponderosa pines, the standard deviation of the detection probability is greater than 1/2 the mean; we

question whether a mean probability of detecting root disease symptoms of 0.52 with a standard deviation of 0.31 really provides useful information. the situation improves when sampling lodgepole pines. Here, the mean probability of detecting symptomatic roots is 0.75 ± 0.32. Sampling additional roots reduces the variation, primarily because the probability of detecting symptoms approaches 1.0. The variation is very low in the mixed conifer stand, where the probability is almost 1.0 when sampling 2 or more roots.

If additional roots must be sampled to provide the desired level of accuracy and/or precision, some concerns must be raised. Destroying 2 or more roots on relatively small trees could have a substantial impact on their vigor; it could even lead to (further) invasion of these trees by root disease fungi. If these trees are to be sampled repeatedly, a less destructive sampling technique must be applied.

Table 1. Root disease condition of roots from all Ponderosa Pines sampled in Northern California.

	Number of Roots		
Direction	Uninfected	Infected within 1m	Infected beyond 1m
North	17	12	8
South	18	16	11
East	6	15	8
West	21	12	4

Table 2. Probability of detecting a symptomatic root sampling roots from all ponderosa pines studied in California

Number of roots in sample	Directions	Probability
1	N	.34
2	N,S	.56
3	N,S,E	.80
4	N,S,E,W	.87

Table 3. Root disease condition of roots from all lodgepole pines sampled for *Armillaria* in northern Utah.

	Number of Roots		
Direction	Uninfected	Infected within 1m	Infected beyond 1m
North	20	23	3
South	18	22	2
East	15	24	0
West	25	35	1

Table 4. Probability of detecting a symptomatic root sampling roots from all lodgepole pines studied in northern Utah.

Number of roots in sample	Directions	Probability
1	N	.50
2	N,S	.77
3	N,S,E	.82
4	N,S,E,W	.93

Table 5. Root disease condition of roots from all Douglas-fir and grand firs in sampled in northern Idaho.

Direction	Number of Roots: Uninfected	Infected within 1m	Infected beyond 1m
North	10	37	0
South	11	46	2
East	2	31	0
West	5	43	2

Table 6. Probability of detecting a symptomatic root sampling roots from all trees studied in northern Idaho

Number of roots in sample	Directions	Probability
1	N	.79
2	N,S	.96
3	N,S,E	1.00
4	N,S,E,W	1.00

Table 7. Probability of detecting root disease symptoms in ponderosa pines by exposing one or more roots to a distance of 1 meter.

	Quadrant sampled				%Roots
Tree	N	N+S	N+S+E	N+S+E+W	with symptoms
1-1	0.25	0.38	0.73	0.77	62
1-2	0.33	0.52	0.52	0.62	99
1-3	0.25	0.46	0.46	0.56	34
2-1	0.50	1.00	1.00	1.00	69
2-2	0.50	0.60	0.83	0.87	27
2-3	0.50	0.50	---	0.50	4
4-1	0.50	---	---	---	50
4-3[2]	0.00	0.00	0.55	---	100
4-4	0.33	0.79	0.90	---	36
4-5	0.40	1.00	1.00	1.00	22
4-6	0.00	0.00	---	---	100
[1]Mean	0.32	0.52	0.63	0.66	54
Stand. Dev.	0.17	0.31	0.28	0.27	32

[1] Where --- occur in the data set, the value to the immediate left in the table was used to compute means and standard deviations.

[2]Trees 4-3 and 4-4 are junipers.

Table 8. Probability of detecting symptoms of Armillaria in lodgepole pines by exposing one or more roots to a distance of 1 meter.

	Quadrant sampled				%Roots
Tree	N	N+S	N+S+E	N+S+E+W	with symptoms
1-1	0.00	0.80	0.80	1.00	52.4
1-6	0.00	0.00	0.63	0.63	10.4
1-16	1.00	1.00	1.00	1.00	32.3
2-1	0.33	0.84	0.90	---	11.6
2-2	---	---	---	0.50	19.7
2-3	1.00	1.00	1.00	1.00	8.3
2-4	1.00	1.00	1.00	1.00	4.4
2-5	1.00	1.00	1.00	1.00	5.7
3-1	0.66	0.84	1.00	1.00	16.5
3-2	0.25	1.00	1.00	1.00	5.9
3-3	0.75	0.95	0.97	1.00	15.7
4-1	0.00	1.00	1.00	1.00	16.0
4-2	0.33	0.67	0.79	0.93	20.7
4-3	0.33	0.33	1.00	1.00	4.7
4-4	0.50	---	1.00	1.00	13.0
5-1	1.00	1.00	1.00	1.00	32.3
5-2	0.40	---	1.00	1.00	15.5
5-3	1.00	1.00	1.00	1.00	39.5
6-1	0.33	0.79	0.86	1.00	14.0
6-2	0.33	1.00	1.00	1.00	47.5
[1]Mean	0.51	0.75	0.89	0.94	19.3
Stand.Dev.	0.37	0.32	0.22	0.13	13.8

[1] Where --- occur in the data set, the value to the immediate left in the table was used to compute means and standard deviations.

Table 9. Probability of detecting symptoms of root disease in Douglas-fir and grand firs by exposing one or more roots to a distance of 1 meter.

	Quadrant sampled				%Roots
Tree	N	N+S	N+S+E	N+S+E+W	with symptoms
1-1	0.00	0.50	---	0.94	29
1-2	1.00	1.00	1.00	1.00	16
1-4	1.00	---	1.00	1.00	50
1-5	0.66	---	---	---	26
1-6	0.50	0.50	---	---	15
2-1	---	1.00	---	---	55
2-2	0.86	0.98	1.00	1.00	58
2-3	1.00	1.00	---	1.00	84
2-4	---	1.00	---	1.00	48
2-6	---	---	1.00	---	100
2-7	1.00	1.00	1.00	1.00	55
3-1	0.60	1.00	1.00	1.00	35
3-2	1.00	1.00	---	---	59
3-3	1.00	1.00	1.00	1.00	91
3-4	1.00	1.00	1.00	1.00	27
[1]Mean	0.64	0.84	0.91	0.94	49
Stand.Dev.	0.41	0.28	0.18	0.14	25

[1] Where --- occur in the data set, the value to the immediate left in the table was used to compute means and standard deviations.

Table 10. Parameters of regression of probability of detection on proportion of roots with symptoms for ponderosa pines with <u>Heterobasidion annosum</u>.

Number of roots in sample	Directions	Slope	Intercept	r^2
1	N	-1.87	20.26	0.002
2	N,S	9.28	12.29	0.048
3	N,S,E	-2.29	21.36	0.001
4	N,S,E,W	10.84	9.03	0.011

Table 11. Parameters of regression of probability of detection on proportion of roots with symptoms for lodgepole pines with <u>Armillaria</u> root disease.

Number of roots in sample	Directions	Slope	Intercept	r^2
1	N	-1.22	0.94	0.453
2	N,S	-0.56	0.84	0.300
3	N,S,E	-0.49	0.86	0.183
4	N,S,E,W	-0.48	0.87	0.174

Table 10. Parameters of regression of probability of detection on proportion of roots with symptoms for Douglas-firs and grand firs.

roots in sample	Directions	Slope	Intercept	r^2
1	N	-0.83	50.40	0.000
2	N,S	-11.50	59.56	0.017
3	N,S,E	72.56	-16.21	0.269
4	N,S,E,W	85.02	-30.06	0.235

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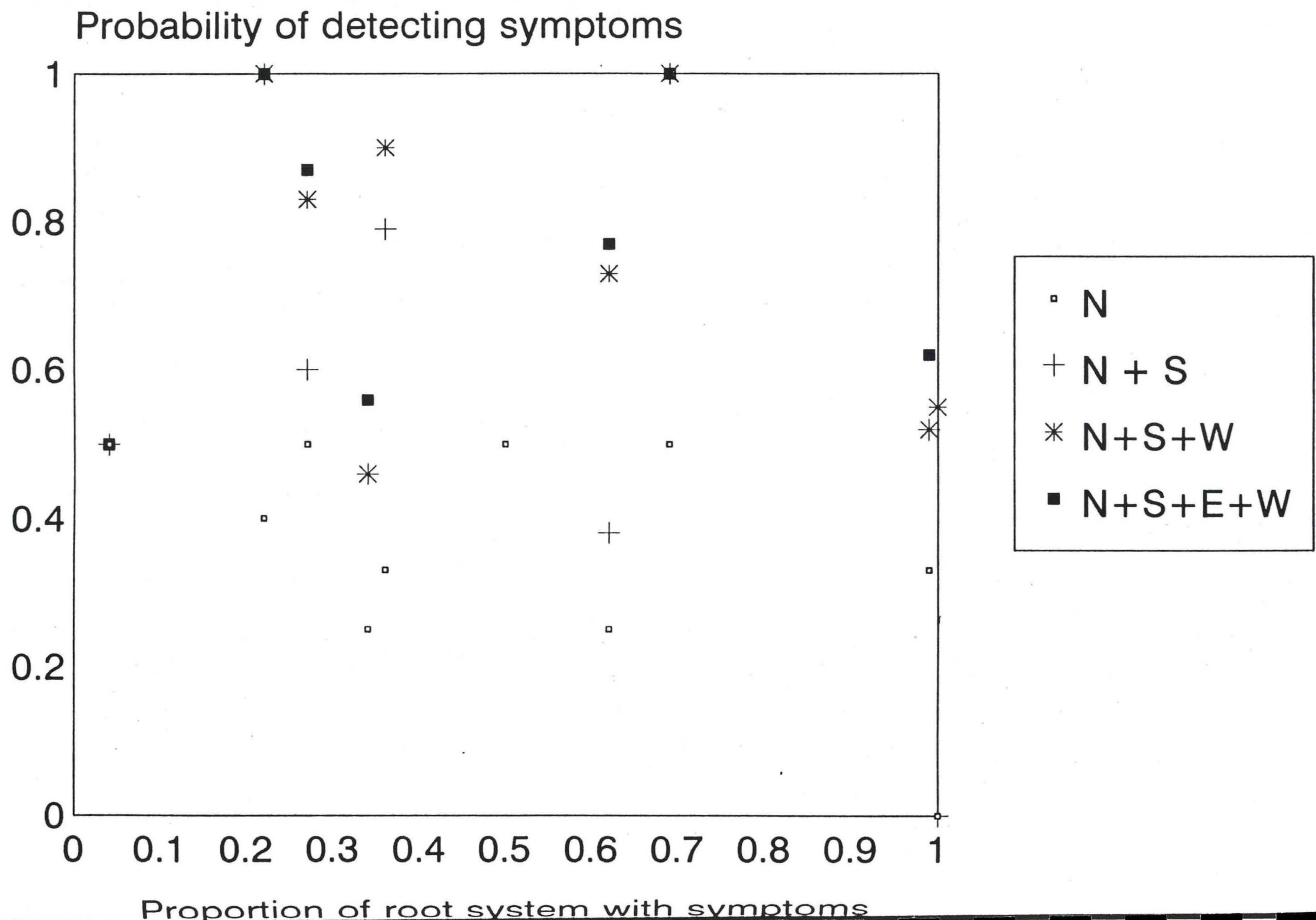
Figure 1. Scatter plot of probability of detecting symptoms by sampling 1-4 roots vs. proportion of root system with symptoms for ponderosa pines infested with <u>Heterobasidi annosum.</u>



Probability of detecting symptoms
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
N
N + S
N+S+W
N+S+E+W
Proportion of root system with symptoms

Figure 2. Scatter plot of probability of detecting symptoms by sampling 1-4 roots vs. proportion of root system with symptoms for lodgepole pines infested with Armillaria.

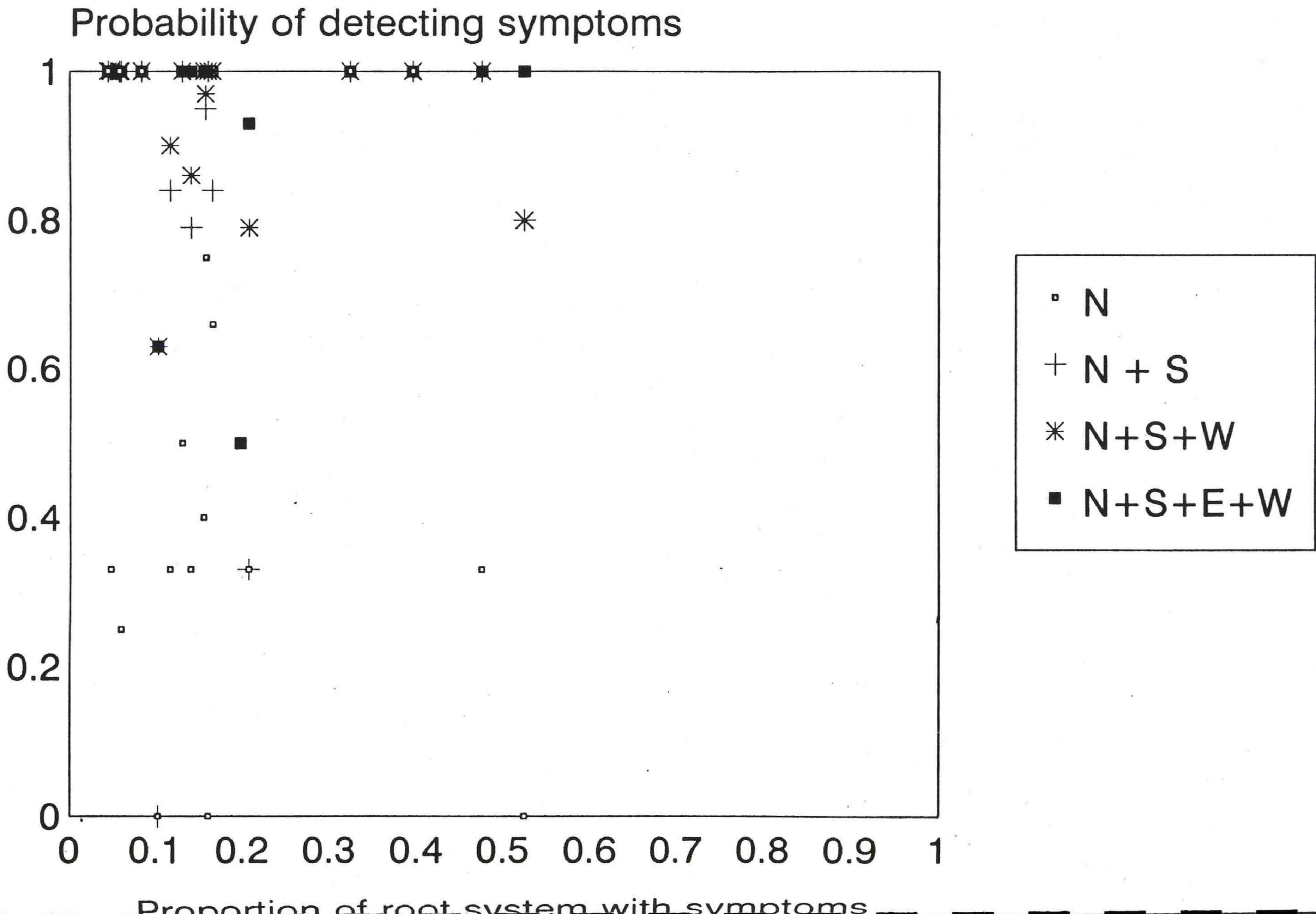
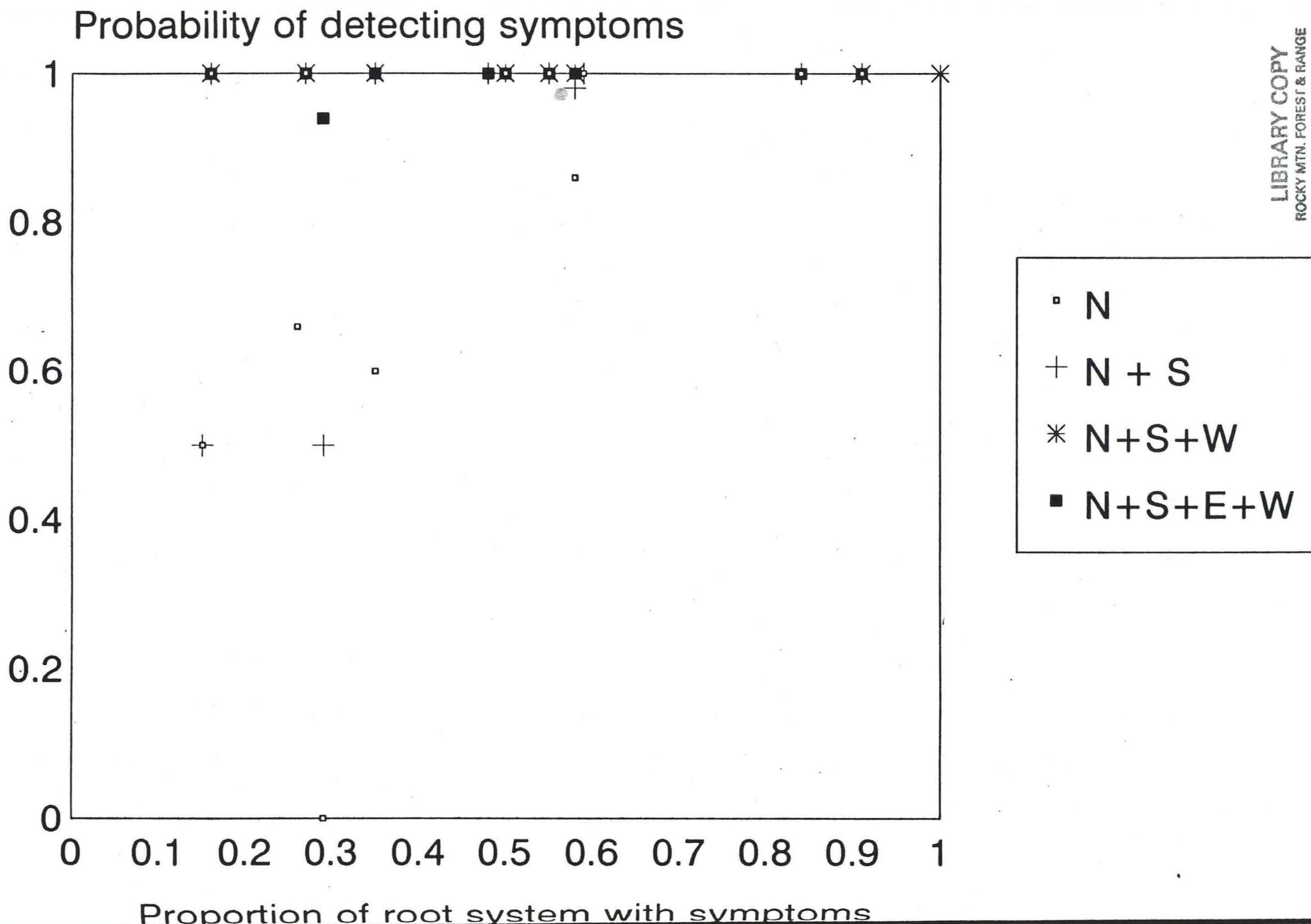

Probability of detecting symptoms
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
N
N + S
N+S+W
N+S+E+W
Proportion of root system with symptoms

Figure 3. Scatter plot of probability of detecting symptoms by sampling 1-4 roots vs. proportion of root system with symptoms for Douglas-firs and grand firs infested with root disease complex.



Probability of detecting symptoms
1
0.8
0.6
0.4
0.2
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
N
N + S
N+S+W
N+S+E+W
Proportion of root system with symptoms

Appendix 1. Probability of sampling a symptomatic root for each Ponderosa Pine examined in Northern California

			Infected	
Tree	Direction	Uninfected	within 1m	beyond 1m
1-1	N	6	3	3
	S	2	4	2
	E	4	2	3
	W	4	1	2
1-2	N	2	1	0
	S	5	1	1
	E	4	0	1
	W	4	1	0
	-	1	0	0
1-3	N	3	1	0
	S	5	1	1
	E	3	0	0
	W	5	1	0
	-	4	0	0
2-1	N	2	2	0
	S	0	3	0
	E	2	1	0
	W	1	5	0
2-2	N	1	1	0
	S	2	1	2
	E	2	4	1
	W	2	1	2
	-	1	0	0
2-3	N	1	1	0
	S	2	0	0
	E	0	0	0
	W	4	0	0
4-1	N	0	0	0
	S	0	0	0
	E	0	0	0
	W	0	0	0
	-	1	2	1
4-3	N	1	0	0
	S	1	0	0
	E	4	6	1
	W	0	0	0
4-4	N	0	1	2
	S	1	2	0
	E	1	2	1
	W	0	0	0

Appendix 1 (continued). Probability of sampling a symptomatic root for each Ponderosa Pine examined in Northern California

Tree	Direction	Uninfected	Infected within 1m	Infected beyond 1m
4-5	N	1	2	2
	S	0	1	0
	E	5	0	1
	W	0	0	0
4-6	N	0	0	1
	S	0	0	2
	E	0	0	0
	W	0	0	0
5-1	N	0	0	0
	S	0	3	3
	E	1	0	0
	W	1	3	0
5-2	N	5	0	0
	S	10	0	0
	E	0	0	0
	W	0	0	0
5-3	N	4	0	0
	S	3	0	0
	E	0	0	0
	W	0	0	0

Appendix 2. Probability of sampling a symptomatic root for each lodgepole Pine examined in Northern Utah

Tree	Direction	Uninfected	Infected within 1m	Infected beyond 1m
1-1	N	1	0	0
	S	1	4	0
	E	1	0	0
	W	0	2	0
1-6	N	0	0	1
	S	4	0	0
	E	3	5	0
	W	2	0	0
1-16	N	0	1	0
	S	1	1	1
	E	0	0	0
	W	0	2	0
2-1	N	2	1	0
	S	1	3	0
	E	2	1	0
	W	0	0	0
2-2	N	0	0	0
	S	0	0	0
	E	0	0	0
	W	3	3	0
2-3	N	0	1	0
	S	0	0	0
	E	1	1	0
	W	2	2	0
2-4	N	0	2	0
	S	1	0	0
	E	0	0	0
	W	5	0	0
2-5	N	0	1	1
	S	2	1	0
	E	0	0	0
	W	2	0	0
3-1	N	1	2	0
	S	0	1	1
	E	0	1	0
	W	2	3	0

Appendix 2 (continued). Probability of sampling a symptomatic root for each lodgepole Pine examined in Northern Utah.

Tree	Direction	Uninfected	Infected within 1m	Infected beyond 1m
3-2	N	3	1	0
	S	0	1	0
	E	2	0	0
	W	1	3	0
3-3	N	1	3	0
	S	5	2	0
	E	2	2	0
	W	0	4	0
4-1	N	2	0	0
	S	0	2	0
	E	1	3	0
	W	1	1	0
4-2	N	1	1	1
	S	1	1	0
	E	2	1	0
	W	0	2	1
4-3	N	2	1	0
	S	1	0	0
	E	0	1	0
	W	4	1	0
4-4	N	1	1	0
	S	0	0	0
	E	0	2	0
	W	1	0	0
5-1	N	0	2	0
	S	0	1	0
	E	0	1	0
	W	0	3	0
5-2	N	3	2	0
	S	0	0	0
	E	0	1	0
	W	1	3	0
5-3	N	0	2	0
	S	0	1	0
	E	0	2	0
	W	0	3	0

Appendix 2 (continued). Probability of sampling a symptomatic root for each lodgepole Pine examined in Northern Utah

Tree	Direction	Uninfected	Infected within 1m	beyond 1m
6-1	N	1	1	1
	S	1	2	0
	E	1	1	1
	W	0	2	0
6-2	N	2	1	0
	S	0	2	0
	E	0	2	1
	W	1	1	0

Appendix 3. Probability of sampling a symptomatic root for each Douglas-fir or grand fir examined in Northern Idaho.

			Infected	
Tree	Direction	Uninfected	within 1m	beyond 1m
1-1	N	1	0	1
	S	1	1	0
	E	0	0	0
	W	1	2	0
1-2	N	0	1	0
	S	0	0	0
	E	1	3	0
	W	0	1	1
1-4	N	0	2	0
	S	0	0	0
	E	0	1	0
	W	0	6	0
1-5	N	1	2	0
	S	0	0	0
	E	0	0	0
	W	0	0	0
1-6	N	3	3	0
	S	6	0	0
	E	0	0	0
	W	0	0	0
2-1	N	0	0	0
	S	0	1	0
	E	0	0	0
	W	1	8	0
2-2	N	1	6	0
	S	1	5	0
	E	0	2	0
	W	0	5	0
2-3	N	0	2	0
	S	0	3	0
	E	0	0	0
	W	0	1	0
2-4	N	0	0	0
	S	0	3	0
	E	0	0	0
	W	0	1	1
2-6	N	0	0	0
	S	0	0	0
	E	0	1	0
	W	0	0	0

Appendix 3 (continued). Probability of sampling a symptomatic root for each Douglas-fir or grand fir examined in Northern Idaho.

Tree	Direction	Uninfected	Infected within 1m	Infected beyond 1m
2-7	N	0	1	0
	S	0	7	0
	E	0	1	0
	W	0	3	0
3-1	N	4	0	6
	S	0	3	0
	E	1	5	0
	W	3	5	0
3-2	N	0	12	0
	S	1	16	0
	E	0	12	0
	W	0	5	0
3-3	N	0	1	0
	S	0	3	1
	E	0	2	0
	W	0	3	0
3-4	N	0	1	0
	S	2	3	0
	E	0	4	0
	W	0	3	0